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### (54) MAGNETRON SPUTTER ION PLATING

IONENPLATTIERUNG MITTELS MAGNETRONSPUTTERN

PLACAGE IONIQUE A PULVERISATION PAR MAGNETRONS

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- **PATENT ABSTRACTS OF JAPAN vol. 13, no. 457 (C-644)(3805) October 16, 1989 & JP- A-1 176 073 (FUJITSU ) July 12, 1989 see figure 3**
- **PATENT ABSTRACTS OF JAPAN vol. 11, no. 3 (C-395)(2450) January 7, 1987 & JP-A- 61 179 864 (HITACHI ) August 12, 1986 see the whole document**
- **B. Chapman, "Glow Discharge Processes", New York: John Wiley & Sons, 1980, 214-219**

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## Description

This invention relates to equipment for the Physical Vapour Deposition technique of magnetron sputter ion plating, that is to say for depositing materials in atomic and/or ionic form onto a receiving substrate by electrical discharge, for example to form coatings.

Sputtering is a well known process in which a cathode of a glow discharge is made the target of ions produced in the glow discharge in a surrounding low-pressure gas. The ions are accelerated towards the target by an electric field and the impact of them on the target displaces particles of the surface of the target; these particles are deposited on the surface of a suitably placed substrate to form the coating.

It is known that the intensity of the glow discharge can be increased significantly by the so-called magnetron effect, which causes the ionisation electrons to be trapped in a region where the electric field is crossed by an added magnetic field. This is the basis of magnetron sputtering, which gives deposition rates approximately ten times those from non-magnetron electrodes and also allows sputtering to take place at much lower gas pressures. Magnets are placed to produce lines of force passing across and above the surface of the target.

From JP-A-61-179 864 (PATENT ABSTRACTS OF JAPAN vol. 11 No. 3 (C-395)(2450) January 7, 1987) a sputtering apparatus and method is known having two magnetron type targets each having an inner pole and an outer ring pole of opposite polarity and the outer ring pole of one magnetron being of opposite polarity to the outer ring pole of the other magnetron. The magnetrons comprise a target of source material for the coating covering their exposed faces. These front sputtering surfaces are adjacent and are mutually angled towards the surface of the substrate. The substrate is not electrically biased. The magnetic field lines generated by the magnetrons are confined to the locality of front surfaces of the targets and do not serve to prevent the escape of ionising electrons.

Ion plating is a well known process in which a metal vapour produced in a vacuum system is deposited onto a substrate whilst simultaneously the substrate is bombarded with ions. The ion bombardment improves both the adhesion and the structure of the coating.

The metal vapour for ion plating can be produced by several techniques including sputtering. If sputtering is used as the vapour source in ion plating the technique is called sputter ion plating. If magnetron sputtering is used as the vapour source in ion plating the technique is called magnetron sputter ion plating.

In ion plating the ions which bombard the sample during deposition can be produced by several methods. In the basic ion plating method the ions are produced in an abnormal glow discharge with the samples acting as cathode. This is an inefficient process and typically less than 1 atom in 1000 is ionised in an abnormal glow discharge. The ion current to the samples is low, and is not

sufficient to produce the dense coatings required in many applications, even though the samples are held at a high negative potential.

The ionisation can be increased in several ways.

- 5 For example, the supply of ionising electrons can be increased by means of a hot filament and an electrode which is positive with respect to the filament, or a hollow cathode can also be used to provide a copious supply of electrons.
- 10 Rather than use additional filaments and electrodes to provide ionisation enhancement, it is convenient to use a vapour source that itself can act as a source of ionisation.
- 15 A hot filament electron beam gun evaporator, a resistance heated crucible, and a simple diode sputter electrode are commonly used deposition sources that create little extra ionisation. On the other hand, hollow cathode electron beam guns, glow discharge beam guns and arc sources all produce intense ionisation at
- 20 a level of over 50% ionisation without the need for additional ionisation enhancement devices, and consequently can be used to produce very dense coatings in ion plating systems.

- 25 Magnetron sputtering electrodes have been used in ion plating systems and they do increase the ionisation, but in the past this has not been sufficient to affect the coating structure and to produce dense coatings.

- 30 A recent development has been the unbalanced magnetron which has inner and outer magnets and in which the field strength of the outer magnets is much higher than the field strength of the inner magnets. The 'extra' field lines leaving the outer magnets trap electrons escaping from the magnetron discharge and prevent them from drifting to the various earthed parts of
- 35 the chamber. These electrons cause ionisation in the vicinity of the electrically biased substrate and the ions so formed are attracted to the substrate by the substrate bias, and the substrates receive a higher ion current than in a situation where the magnetrons are balanced.
- 40 However, the intensity of ionisation may still be less than is desirable for the deposition of dense coatings, unless the outer magnets are made exceptionally strong.

- 45 It is thus clear that there are many ways of creating ions for sputtering or ion plating.

- 45 The aim of the invention is to provide an improved magnetron sputter ion plating system, with an increased intensity of useful ionisation.

- 50 According to the invention we provide a magnetron sputter ion plating system comprising electric field means for producing an electric field directed towards a substrate to be coated, biasing means adapted in use to bias the substrate negatively, so as to make it a cathode so as to attract ions, and magnetic field means, the magnetic field means comprising a first and a second magnetron, each having an inner pole and an outer ring pole of opposite polarity, and the magnetrons each comprising a target of source material from which a coating flux is produced, and in which the magnetrons are so

arranged that the outer ring pole of one magnetron and the outer ring pole of the other, or another, magnetron are disposed adjacent to each other and are of opposite polarities, and in which at least one of said first and second magnetrons comprises an unbalanced magnetron arranged such that in use a magnetic field extends between the outer ring poles of the magnetrons linking them so as to prevent the escape of electrons from the system between the magnetrons so that these electrons are not lost to the system and are available to give an increase to the ionisation at the electrically biased substrate.

It will be appreciated that magnetrons having an inner pole and an outer ring pole are well known. The inner pole can be a single magnet, or a line or group of magnets. The outer "ring" pole can be formed from a single magnet or several separate magnets side by side. The "ring" need not be cylindrical or circular, but could be of square or rectangular shape, or indeed any suitable figure.

The linking of the two magnetrons by magnetic flux traps electrons in the system and increases the amount of ionisation which occurs. We can thus provide practical magnetron sputter ion plating systems that give significantly increased ionisation using an unbalanced magnetron.

Preferably the outer, ring, poles are angularly spaced relative to the position of the substrate to be coated so that they subtend a substantial angle at that substrate.

The system may comprise a plurality of magnetrons the adjacent outer poles, or end regions, of which are of opposite polarities. The magnetrons are preferably arranged around the substrate and the substrate may have a generally central position between the magnetrons. Preferably the magnetrons are equally-angularly spaced in a polygon or ring around the substrate.

The electric field may be provided extending substantially radially between the substrate and the magnetrons the substrate being at a negative electrical potential. The negative potential of the substrate may vary from zero up to substantially higher values, say -1000V.

The magnetron poles may comprise a target of source material from which ions are produced.

Preferably there are an even number of magnetrons.

The system may further comprise a pumping port to control the pressure of an ionising gas, such as argon, in the system.

According to a second aspect the invention comprises a method of magnetron sputter ion plating a substrate to be coated comprising providing a first magnetron having an inner ring pole and an outer ring pole of opposite polarity, and a second magnetron having an inner and outer ring pole of opposite polarity, with the outer ring pole of the first magnetron being of opposite polarity to that of the second magnetron; the magnetrons each comprising a target of source material from

which a coating flux is produced; electrically biasing a substrate to be coated so as to make it a cathode to attract positive ions; and reducing the leakage of electrons from between the magnetrons by arranging for a

5 magnetic field to extend between their outer ring poles, thereby trapping electrons which would otherwise escape between the magnetrons and increasing the coating ion density at the substrate to be coated, and in which the magnetic flux linkage between the magnetrons is increased by the use of unbalanced magnetrons.

In this way the ion density at the electrically biased substrate is significantly increased.

Embodiments of the invention will now be described by way of example only with reference to the accompanying drawings of which:-

Figure 1 schematically illustrates a magnetron sputter ion plating system comprising two magnetrons and illustrating an arrangement of magnetic polarities in accordance with the invention;

Figure 2 schematically illustrates another system and shows the arrangement of magnetic polarities when two magnetrons are placed side by side;

Figure 3 illustrates schematically a practical version of a magnetron sputter ion plating system;

Figure 4 shows the improvement in ion current of the embodiment of Figure 3 in comparison with a known system;

Figure 5 illustrates another practical embodiment of the invention;

Figure 6 shows a magnetron sputter ion plating system similar to that of Figure 3, but modified;

Figure 7 shows a still further embodiment of the invention;

Figure 8 shows another embodiment of the invention which is similar in some ways to that of Figure 1; and

Figure 9 is a graph comparing the ion current to a substrate against the bias voltage applied to the substrate for a number of different magnetron sputtering ion plating systems.

Figures 1 and 2 schematically show the basic concept behind the present invention. Two magnetrons 1 and 2 each have an outer ring magnet 3 and a central core magnet 4. In Figure 1, which may be a practical arrangement, the outer magnet 3 of magnetron 1 is of "south" polarity and the inner core magnet 4 is of "north" polarity (in their regions adjacent a substrate 7). The outer magnet 5 of magnetron 2 is of north polarity and its

core 6 of south polarity (in their 5 regions adjacent the substrate 7). Thus the magnetic field lines of magnetrons 1 and 2 form a continuous barrier, trapping electrons which diffuse from the magnetron plasmas.

Figure 1 also shows an electrically biased substrate 7 to be coated, target shrouds 8 of source material covering the exposed faces of the magnetron poles, and the magnetic field B. The magnetron poles have a soft iron backing plate 9 to complete their internal magnetic circuits.

As will be seen from Figure 1, the magnetic field B fully surrounds the substrate 7 and serves to form a ring within which electrons are trapped. Since the electrons cannot escape the system they are available to enhance the ionisation associated with the electrically biased substrate, creating a higher ion density than was previously possible.

Figure 2 illustrates two magnetron pole assemblies disposed side by side, the magnetic flux B still bridging the gap between the assemblies and preventing the escape of electrons through the gap between them.

Turning to Figure 3, this illustrates a practical form of the invention. Three magnetron pole assemblies 10, 11, 12 are provided approximately equi-angularly spaced with the substrate 7 at the centre of the triangle. Adjacent outer magnetic assemblies of the magnetrons 10 and 12 and 11 and 12 respectively are of opposite polarity. A pumping port 17 is provided between the two adjacent poles of similar polarity of assemblies 10 and 11.

Magnetic field lines 18 extend from the adjacent ends of the magnetrons 10 and 12, and the magnetrons 11 and 12 and prevent the escape of electrons through the gaps between the magnetrons 10 and 12 and 11 and 12. Thus electrons cannot escape to earthed parts of the system, except in the region of the pumping port.

In use an inert gas such as argon is provided in the chamber of the system and electrons are accelerated in the chamber by a potential difference applied to the magnetron targets 8 to ionize the gas, producing more electrons and argon ions. The argon ions present in the chamber bombard the targets 8 of source material and produce a coating flux of source material. The argon ions also bombard the substrate. The magnetic field lines B serve to form a continuous barrier to the electrons diffusing from the magnetron discharges and ensure that these electrons are not lost to the system without performing their useful function of enhancing the glow discharge associated with the negatively electrically biased substrates, increasing the ion current to the substrate.

Figure 4 illustrates the improvement which the present invention can achieve. Line X shows the ion current available for different bias voltages in an arrangement similar to that of Figure 3, but with each magnetron pole assembly being identical (for example, all three magnetrons having outer magnet assemblies with south poles akin to magnetrons 10 and 11) so that there is no

flux between adjacent magnetrons. Line Y shows the ion current produced by the embodiment of Figure 3 which is far higher because of the flux between adjacent assemblies trapping ionising electrons.

Figure 5 shows another practical embodiment of a magnetron sputter ion plating system. Four magnetrons 20 are provided equi-angularly spaced in a ring with the substrate 7 at its centre. Each magnetron is similar to those described in Figure 1 and similar components have been given similar reference numerals. A pumping port (not shown) is provided out of the plane of the four magnetrons, for example the system may have the overall cylindrical shape of a dustbin and the pumping port may be provided at the base of the dustbin, with the magnetrons, and substrate, above the base.

The magnetic field B forms a continuous ring surrounding the substrate and traps electrons in the ring. Since an even number of magnetron pole assemblies is provided the flux ring can be complete. There is an advantage in providing an even number of magnetrons. Six or eight magnetron pole assemblies are also considered good configurations, but clearly more could be provided if desired. Adjacent magnetrons would have outer magnet assemblies of opposite polarity.

Figure 6 illustrates a system similar to that of Figure 3, but modified to alleviate the loss of ionising electrons at the region between the two pole assemblies near to the pumping port. Similar components have been given similar reference numerals. An electrode component 25 is provided between the adjacent poles of the same polarity of magnetrons 10' and 11', with the component 25 providing an additional magnetic pole of opposite polarity between the two similar adjacent poles. The component 25 comprises a magnet 26 and a cap 27 of ferromagnetic material. The electrode component 25 is at a floating potential (it is insulated from earth). The magnetic field lines from magnetrons 10' and 11' are attracted to the magnetic electrode 25, so providing a closed trap for electrons.

The type of additional magnetic electrode shown in Figure 6 can be placed between neighbouring magnetron electrodes of similar polarity in a coating system to provide a barrier to the electrons escaping from the magnetron discharges, and so increase the intensity of ionisation and the ion current to the electrically biased substrates.

Figure 7 illustrates another embodiment of the invention which has six magnetron pole assemblies, with next-neighbour outer pole assemblies having opposite polarity.

Figure 8 shows a magnetron sputter ion plating system having four magnetron pole assemblies 30, 31, 32 and 33. Pole assemblies 30 and 32 have alternate polarities, but pole assembly 33 presents poles of the same polarity to the adjacent portions of pole assemblies 30 and 32. Some magnetic field lines, lines 34, are not closed and escape the system. However, pole assemblies 31 and 33 also have magnetic field lines 35

connecting their regions of opposite polarity. A reasonable degree of magnetic closure still exists and we still achieve increased ionisation.

Even numbers of pole assemblies with next-neighbour assemblies being of opposite polarity are preferred (for example the embodiments of Figures 5 and 7), but other arrangements can work well.

Figure 9 compares the performance of different magnetron sputter ion plating systems. Axis S represents the bias voltage applied to the substrate (in volts), and axis T represents the ion current to the substrate target. Lines 40 to 45 exemplify the performance of magnetron system having the following characteristics:-

- Line 40 - Three pole assemblies (balanced), all of the same polarity and using ferrite magnets.
- Line 41 - Three pole assemblies (unbalanced), all of the same polarity and using ferrite magnets.
- Line 42 - Three mixed or alternating polarity magnetron pole assemblies (unbalanced), with ferrite magnets (as in the embodiment of Figure 3).
- Line 43 - Three mixed or alternating polarity magnetron pole assemblies (unbalanced), with ferrite magnets, plus a dummy, or additional, pole assembly (as in the embodiment of Figure 6).
- Line 44 - Four mixed or alternating polarity magnetron pole assemblies (unbalanced) with ferrite magnets.
- Line 45 - Four mixed or alternating polarity magnetron pole assemblies (unbalanced) with Nd Fe B magnets.

The ionisation enhancement effect of the "mixed" polarity magnetrons is effective even when relatively weak magnets such as ferrites are used. The ionisation enhancement effect is even greater when stronger magnetic materials, such as Neodymium Iron Boron are used.

Arrangements of three and four magnetrons as shown in Figure 3 and 5 have been used for the deposition of titanium nitride and other hard coats. The high ionisation produced by the 'mixed' magnetron effect is important in depositing coatings with high adhesion and hard dense structures.

The ion bombardment of the substrates is due to the ions formed in the glow discharge around the substrates being attracted to the substrates by the negative electrical bias voltage applied to the substrates. This bias voltage can be a DC voltage, or Radio Frequency

power can be applied to the substrates in order to produce an induced negative voltage. The radio frequency technique is necessary when the substrates are of an electrically insulating material and/or when the coating material is electrically insulating, but can also be used when the substrates and the coating material are electrically conducting. The improvements in coating adhesion and structure brought about by the increased ionisation due to the mixed magnetron polarity arrangement occur for both the DC and RF substrate bias.

### Claims

- 15. 1. A magnetron sputter ion plating system comprising electric field means for producing an electric field (E) directed towards a substrate ('7;7') to be coated, biasing means adapted in use to bias the substrate ('7;7') negatively, so as to make it a cathode so as to attract ions, and magnetic field means (1,2; 10,11,12;20), the magnetic field means comprising at least a first and a second magnetron (1,2;10,12), each having an inner pole and an outer ring pole of opposite polarity, and the magnetrons each comprising a target of source material from which a coating flux is produced, and in which the magnetrons are so arranged that the outer ring pole of one magnetron (1;10) and the outer ring pole of the second, or further, magnetron (2;12) are disposed adjacent to each other and are of opposite polarities, and in which at least one of said first and second magnetrons comprises an unbalanced magnetron arranged such that in use a magnetic field (B) extends between the outer ring poles of the magnetrons linking them so as to prevent the escape of electrons from the system between the magnetrons so that these electrons are not lost to the system and are available to give an increase to the ionisation at the electrically biased substrate.
- 20. 2. A system according to claim 1, characterised in that the magnetrons (1,2;10,12) are arranged around the substrate (7;7') and the substrate has a generally central position between the magnetrons.
- 25. 3. A system according to claim 1 or claim 2 characterised in that there are two opposing magnetrons and the substrate is located between the magnetrons.
- 30. 4. A system according to any preceding claim characterised in that the magnetrons are spaced in a polygon or a ring around the substrate.
- 35. 5. A system according to any preceding claim, characterised in that the magnetrons are substantially equally-angularly spaced in a polygon or ring around the substrate.

6. A system according to any preceding claim, characterised in that there are an even number of magnetrons.
7. A system according to any one of claims 1 to 5 characterised in that there are an odd number of magnetrons.
8. A system according to claim 7 in which an additional magnetic electrode is used to close the magnetic field between two adjacent poles of adjacent magnetrons with outer pole pieces of the same polarity.
9. A system according to any preceding claim, characterised in that there are at least three or four magnetrons.
10. A system according to any preceding claim in which there are four magnetrons (31), one having an outer pole of one polarity and the other three (30,32,33) having outer poles of the opposite polarity.
11. A system according to any preceding claim in which there is no magnetic field-generating solenoid coil provided between the adjacent magnetrons (1,2; 10,12).
12. A method of magnetron sputter ion plating a substrate to be coated comprising providing a first magnetron having an inner pole and an outer ring pole of opposite polarity, and a second magnetron having an inner pole and an outer ring pole of opposite polarity, with the outer ring pole of the first magnetron being of opposite polarity to that of the second magnetron; the magnetrons each comprising a target of source material from which a coating flux is produced; electrically biasing a substrate to be coated so as to make it a cathode to attract positive ions; and reducing the leakage of electrons from between the magnetrons by arranging for a magnetic field to extend between their outer ring poles, thereby trapping electrons which would otherwise escape between the magnetrons and increasing the coating ion density at the substrate to be coated, and in which the magnetic flux linkage between the magnetrons is increased by the use of unbalanced magnetrons.

#### Patentansprüche

- System zur Ionenplattierung mittels Magnetronspattern mit elektrischen Feldmitteln zur Erzeugung eines auf ein zu beschichtendes Substrat (7';7') gerichtetes elektrisches Feld (E), Spannungsmitteln, die geeignet sind das Substrat (7';7') negativ zu laden, um es so zu einer Kathode zu machen um so Ionen anzuziehen, und magnetischen Feldmitteln
- (1,2;10,11,12; 20), wobei die magnetischen Feldmittel mindestens ein erstes und ein zweites Magnetron (1,2;10,12), wobei jedes einen inneren Pol und einen äußeren Ringpol entgegengesetzter Polarität aufweist, umfaßt und wobei die Magnetrons jeweils ein Target aus Quellenmaterial, von welchem ein Beschichtungsfluß erzeugt wird, umfassen, und in welchem die Magnetrons so angeordnet sind, daß der äußere Ringpol eines Magnetrons (1; 10) und der äußere Ringpol des zweiten oder weiteren Magnetrons (2;12) benachbart zu dem jeweils anderen angeordnet und von entgegengesetzter Polarität sind, und in welchem zumindest eines der ersten und zweiten Magnetrons ein nicht im Gleichgewicht befindliches Magnetron umfaßt, welches derart angeordnet ist, daß im Betrieb ein magnetisches Feld (B) sich zwischen den äußeren Ringpolen der Magnetrons erstreckt, so daß das Entweichen von Elektronen von dem System zwischen den Magnetrons verhindert wird, so daß diese Elektronen nicht an das System verlorengehen und zur Erhöhung der Ionisation an dem elektrisch geladenen Substrat zur Verfügung stehen.
25. System nach Anspruch 1, dadurch gekennzeichnet, daß die Magnetrons (1,2;10,12) um das Substrat (7; 7') angeordnet sind und das Substrat eine im wesentlichen zentrale Position zwischen den Magnetrons hat.
30. System nach Anspruch 1 oder 2, dadurch gekennzeichnet, daß zwei einander gegenüberliegende Magnetrons vorgesehen sind und das Substrat zwischen den Magnetrons angeordnet ist.
35. System nach einem der vorhergehenden Ansprüche, dadurch gekennzeichnet, daß die Magnetrons in einem Polygon oder einem Ring um das Substrat herum angeordnet sind.
40. System nach einem der vorhergehenden Ansprüche, dadurch gekennzeichnet, daß die Magnetrons im wesentlichen gleichwinklig in einem Polygon oder Ring um das Substrat herum angeordnet sind.
45. System nach einem der vorhergehenden Ansprüche, dadurch gekennzeichnet, daß eine gerade Anzahl von Magnetrons vorgesehen ist.
50. System nach einem der Ansprüche 1 bis 5, dadurch gekennzeichnet, daß eine ungerade Anzahl von Magnetrons vorgesehen ist.
55. System nach Anspruch 7, bei welchem eine zusätzliche magnetische Elektrode Verwendung findet um das magnetische Feld zwischen zwei benachbarten Polen von benachbarten Magnetrons mit äußeren Polstücken derselben Polarität zu schließen.

9. System nach einem der vorhergehenden Ansprüche, dadurch gekennzeichnet, daß wenigstens drei oder vier Magnetrons vorgesehen sind.
10. System nach einem der vorhergehenden Ansprüche in welchem vier Magnetrons (31) vorgesehen sind, wobei eines einen äußeren Pol einer Polarität und die anderen drei (30,32,33) äußere Pole der anderen Polarität aufweisen.
11. System nach einem der vorhergehenden Ansprüche, in welchem keine magnetische felderzeugende Solenoidspule zwischen den benachbarten Magnetrons (1,2;10,12) vorgesehen ist.
12. Verfahren zur Ionenplattierung mittels Magnetronputtern zur Beschichtung eines Substrats, mit einem ersten Magnetron mit einem inneren Pol und einem äußeren Ringpol entgegengesetzter Polarität, und mit einem zweiten Magnetron mit einem inneren Pol und einem äußeren Ringpol entgegengesetzter Polarität, wobei: der äußere Ringpol des ersten Magnetrons von entgegengesetzter Polarität zu demjenigen des zweiten Magnetrons ist; die Magnetrons jeweils ein Target aus Quellenmaterial, von welchem ein Beschichtungsfluß erzeugt wird, umfassen; ein zu beschichtendes Substrat elektrisch geladen wird um es zu einer Kathode zu machen um positive Ionen anzuziehen; und das Entweichen von Elektronen von zwischen den Magnetrons reduziert wird, indem für ein magnetisches Feld, welches sich zwischen deren äußeren Ringpolen erstreckt, gesorgt wird, wodurch Elektronen, welche ansonsten zwischen den Magnetrons entweichen würden, eingefangen werden und die Beschichtungsdicke an dem zu beschichtenden Substrat erhöhen, und in welchem die magnetische Flußkopplung zwischen den Magnetrons durch Verwendung von nicht im Gleichgewicht befindlichen Magnetrons erhöht ist.

#### Revendications

1. Système de dépôt ionique par pulvérisation par effet magnétron, comprenant un dispositif à champ électrique destiné à créer un champ électrique (E) dirigé vers un substrat (7 ; 7') qui doit être revêtu, un dispositif de polarisation destiné à être utilisé pour la polarisation du substrat (7 ; 7') de manière négative afin qu'il forme une cathode et attire les ions, et un dispositif à champ magnétique (1, 2 ; 10, 11, 12 ; 20), le dispositif à champ magnétique comprenant au moins un premier et un second magnétron (1, 2 ; 10, 12), ayant chacun un pôle interne et un pôle annulaire externe de polarité opposée, les magnétrons comprenant chacun une cible d'un matériau source à partir duquel un flux de revête-  
ment est produit, et dans lequel les magnétrons sont disposés de manière que le pôle annulaire externe d'un magnétron (1 ; 10) et le pôle annulaire externe du second magnétron ou d'un autre magnétron (2 ; 12) soient adjacents mutuellement et aient des polarités opposées, et dans lequel l'un au moins des premier et second magnétrons est un magnétron déséquilibré disposé de manière que, pendant l'utilisation, un champ magnétique (B) s'étende entre les pôles annulaires externes des magnétrons et les relie en empêchant les électrons de s'échapper du système entre les magnétrons afin que ces électrons ne soient pas perdus pour le système et soient disponibles pour accroître l'ionisation au niveau du substrat polarisé électriquement.
2. Système selon la revendication 1, caractérisé en ce que les magnétrons (1, 2 ; 10, 12) sont disposés autour du substrat (7 ; 7'), et le substrat a une position centrale de façon générale entre les magnétrons.
3. Système selon la revendication 1 ou 2, caractérisé en ce qu'il comporte deux magnétrons opposés et le substrat est placé entre les magnétrons.
4. Système selon l'une quelconque des revendications précédentes, caractérisé en ce que les magnétrons sont espacés sous forme d'un polygone ou d'un anneau formé autour du substrat.
5. Système selon l'une quelconque des revendications précédentes, caractérisé en ce que les magnétrons ont des espacements angulaires pratiquement égaux sous forme d'un polygone ou d'un anneau autour du substrat.
6. Système selon l'une quelconque des revendications précédentes, caractérisé en ce que le nombre de magnétrons est pair.
7. Système selon l'une quelconque des revendications 1 à 5, caractérisé en ce que le nombre de magnétrons est impair.
8. Système selon la revendication 7, dans lequel une électrode magnétique supplémentaire est utilisée pour la fermeture du champ magnétique entre deux pôles adjacents de magnétrons adjacents ayant des pièces polaires externes de même polarité.
9. Système selon l'une quelconque des revendications précédentes, caractérisé en ce qu'il comporte au moins trois ou quatre magnétrons.
10. Système selon l'une quelconque des revendications précédentes, dans lequel quatre magnétrons

(31) sont incorporés, un magnétron ayant un pôle externe d'une polarité et les trois autres (30, 32, 33) ayant des pôles externes de la polarité opposée.

11. Système selon l'une quelconque des revendications précédentes; dans lequel il n'existe aucun enroulement générateur de champ magnétique entre les magnétrons adjacents (1, 2 ; 10, 12). 5

12. Procédé de dépôt ionique par pulvérisation par effet magnétron sur un substrat à revêtir, comprenant la disposition d'un premier magnétron ayant un pôle interne et un pôle annulaire externe de polarité opposée, et un second magnétron ayant un pôle interne et un pôle annulaire externe de polarité opposée, le pôle annulaire externe du premier magnétron ayant une polarité opposée à celle du second magnétron, les magnétrons comprenant chacun une cible d'un matériau source à partir duquel est produit un flux de revêtement, la polarisation électrique d'un substrat à revêtir afin qu'il forme une cathode destinée à attirer des ions positifs, et la réduction de la fuite des électrons entre les magnétrons par disposition d'un champ magnétique entre les pôles annulaires externes, si bien que les électrons qui pourraient s'échapper entre les magnétrons sont piégés et la densité des ions de revêtement au niveau du substrat à revêtir est accrue, et dans lequel la liaison du flux magnétique entre les magnétrons est accrue par utilisation de magnétrons déséquilibrés. 10  
15  
20  
25  
30

35

40

45

50

55

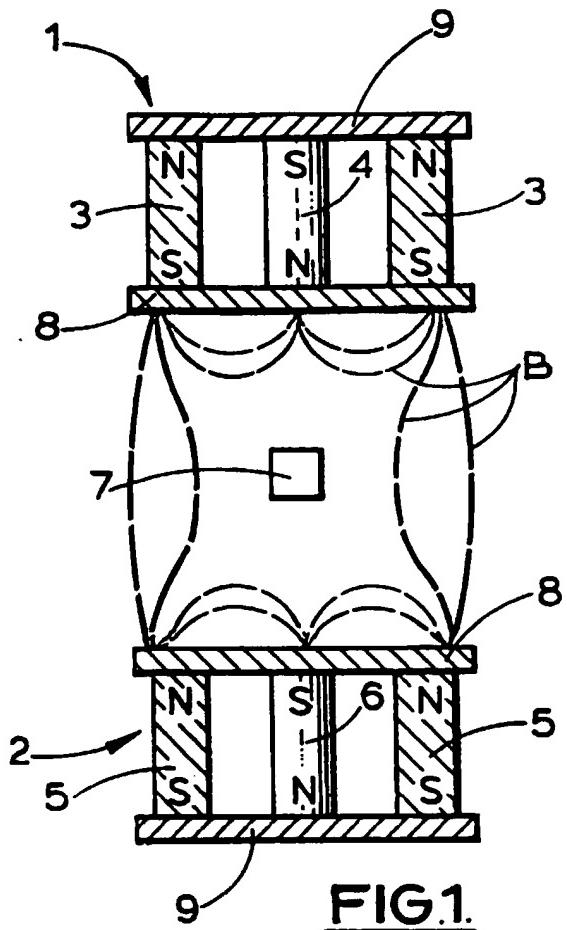


FIG.1.

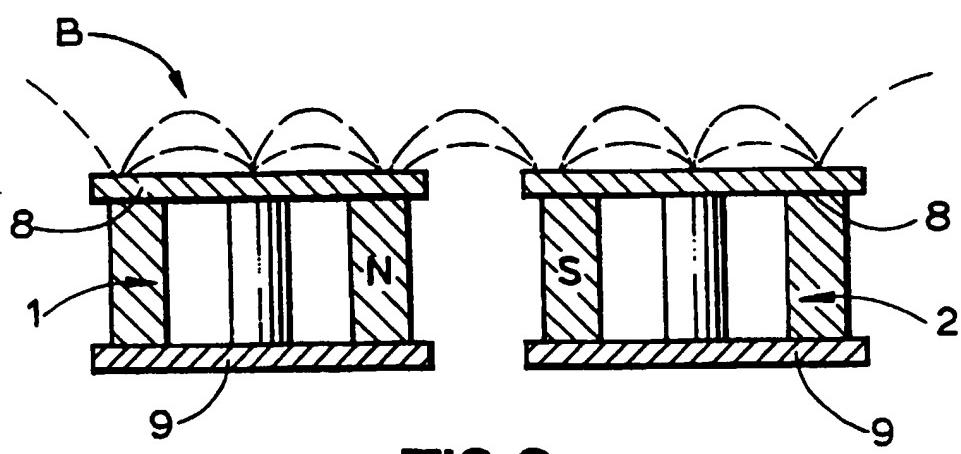
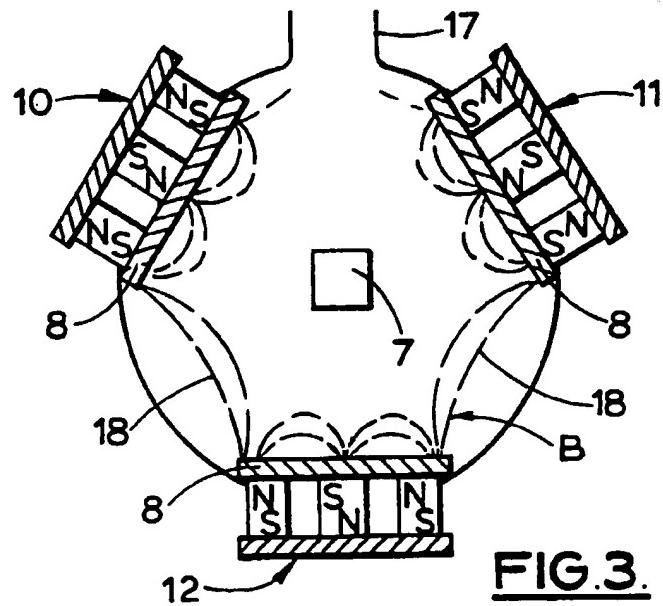
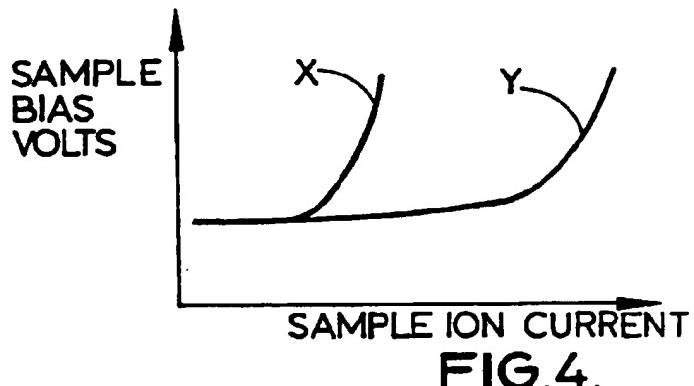
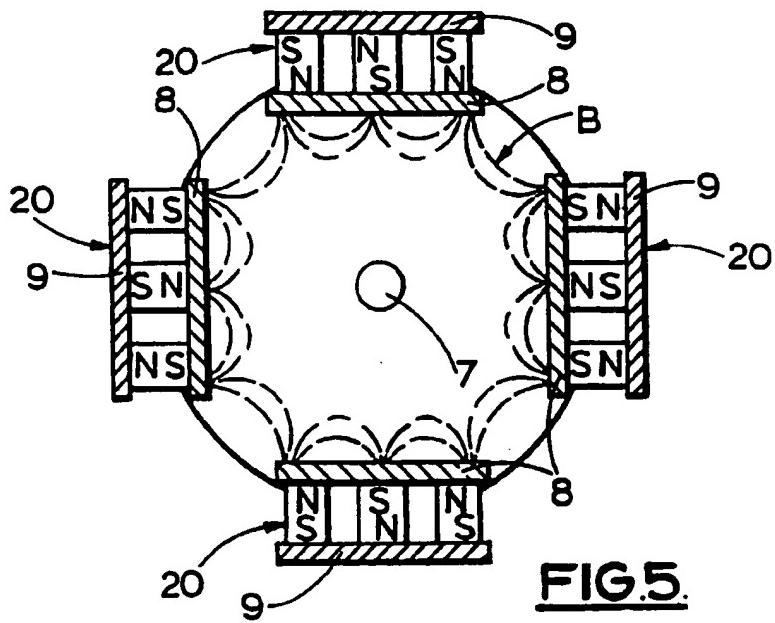
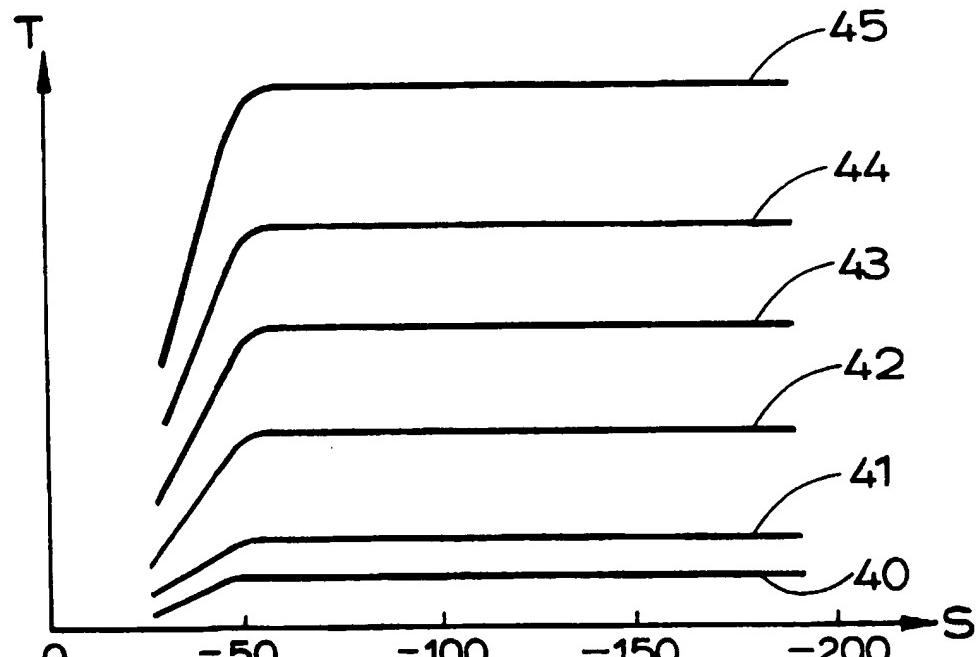
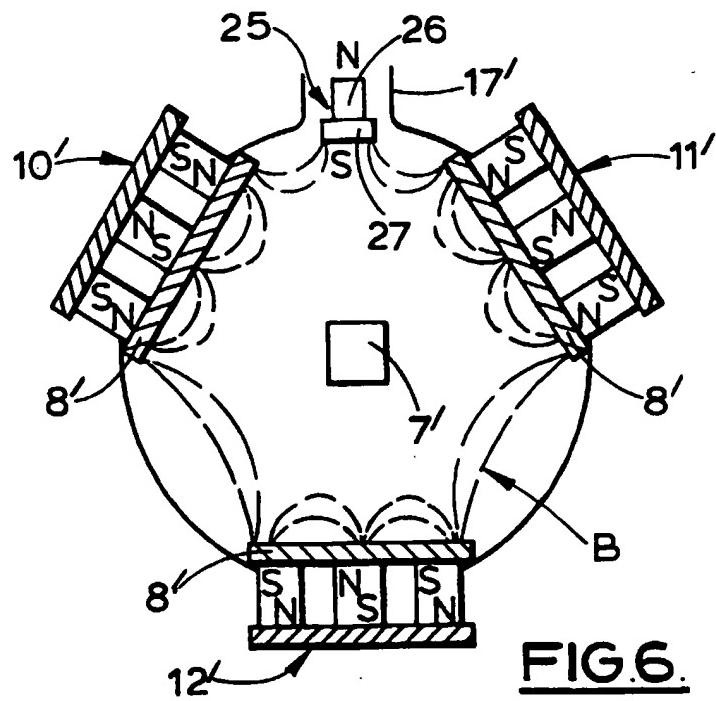


FIG.2.

**FIG.3.****FIG.4.****FIG.5.**

**FIG. 9.**

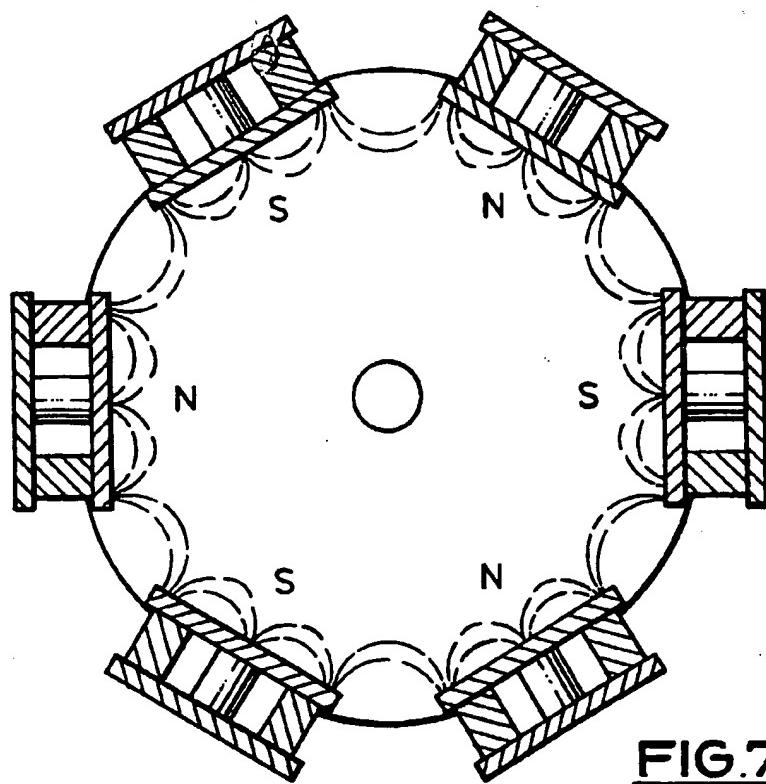


FIG.7.

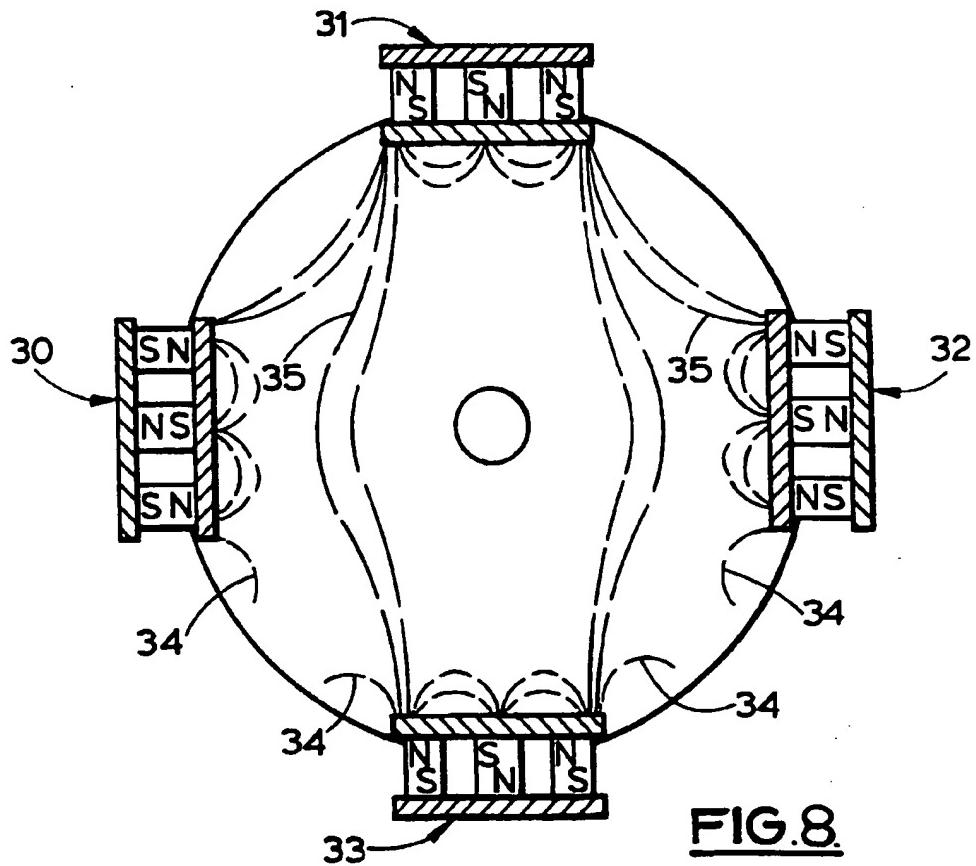


FIG.8.